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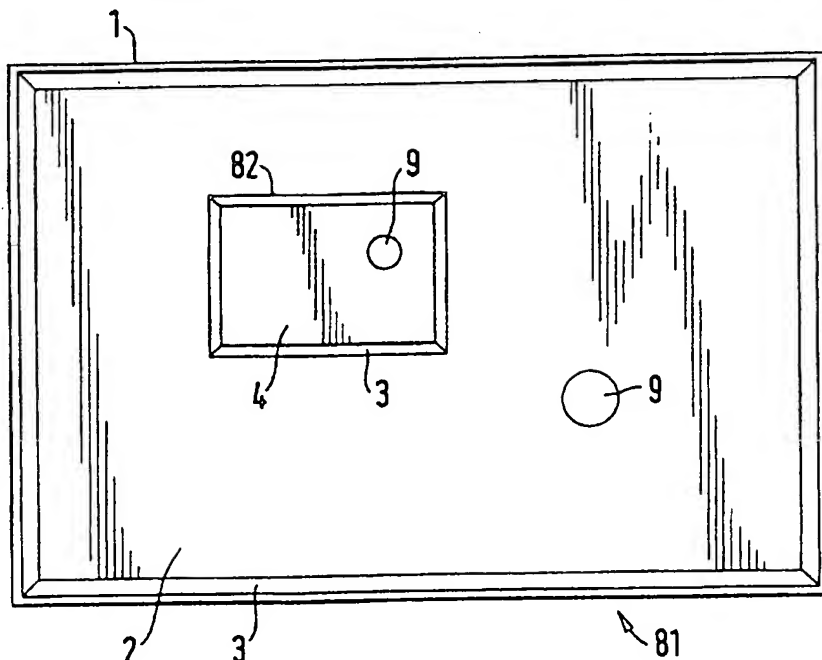
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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			(43) International Publication Date: 13 March 1997 (13.03.97)
(21) International Application Number: PCT/GB96/02162 (22) International Filing Date: 2 September 1996 (02.09.96) (30) Priority Data: 9517918.0      2 September 1995 (02.09.95)      GB 9522281.6      31 October 1995 (31.10.95)      GB 9606836.6      30 March 1996 (30.03.96)      GB (71) Applicant (for all designated States except US): VERITY GROUP PLC [GB/GB]; Stonehill, Huntingdon, Cambridgeshire PE18 6ED (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): AZIMA, Henry [CA/GB]; 3 Southacre Close, Chaucer Road, Cambridge CB2 2TT (GB). COLLOMS, Martin [GB/GB]; 22 Burgess Hill, London NW2 2DA (GB). HARRIS, Neil [GB/GB]; 9 Davey Crescent, Great Shelford, Cambridge CB2 5JF (GB). (74) Agent: MAGUIRE & CO.; 5 Crown Street, St. Ives, Cambridgeshire PE17 4EB (GB).		(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.	

(54) Title: PANEL-FORM LOUDSPEAKERS



## (57) Abstract

A panel-form loudspeaker (81) having a distributed mode acoustic radiator (2, 4) and a first transducer (9) coupled to the radiator (2) to excite distributed mode resonance in the radiator, characterised by a second transducer (9) coupled to vibrate the radiator (14).

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TITLE: PANEL-FORM LOUDSPEAKERS

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DESCRIPTION

15

TECHNICAL FIELD

The invention relates to loudspeakers and more particularly to loudspeakers comprising panel-form acoustic radiating elements.

BACKGROUND ART

20

It is known from GB-A-2262861 to suggest a panel-form loudspeaker comprising:-

a resonant multi-mode radiator element being a unitary sandwich panel formed of two skins of material with a spacing core of transverse cellular construction, wherein  
25 the panel is such as to have ratio of bending stiffness (B), in all orientations, to the cube power of panel mass per unit surface area ( $\mu$ ) of at least 10;

a mounting means which supports the panel or attaches

to it a supporting body, in a free undamped manner;

and an electro-mechanical drive means coupled to the panel which serves to excite a multi-modal resonance in the radiator panel in response to an electrical input within a  
5 working frequency band for the loudspeaker.

#### DISCLOSURE OF INVENTION

Embodiments of the present invention use members of nature, structure and configuration achievable generally and/or specifically by implementing teachings of our co-  
10 pending PCT application no. (our case P.5711) of even date herewith. Such members thus have capability to sustain and propagate input vibrational energy by bending waves in operative area(s) extending transversely of thickness often but not necessarily to edges of the member(s); are  
15 configured with or without anisotropy of bending stiffness to have resonant mode vibration components distributed over said area(s) beneficially for acoustic coupling with ambient air; and have predetermined preferential locations or sites within said area for transducer means,  
20 particularly operationally active or moving part(s) thereof effective in relation to acoustic vibrational activity in said area(s) and signals, usually electrical, corresponding to acoustic content of such vibrational activity. Uses are envisaged in co-pending International application No. (our  
25 file P.5711) of even date herewith for such members as or in "passive" acoustic devices without transducer means, such as for reverberation or for acoustic filtering or for acoustically "voicing" a space or room; and as or in

"active" acoustic devices with transducer means, such as in a remarkably wide range of sources of sound or loudspeakers when supplied with input signals to be converted to said sound, or in such as microphones when exposed to sound to  
5 be converted into other signals.

This invention is particularly concerned with active acoustic devices in the form of loudspeakers.

Members as above are herein called distributed mode acoustic radiators and are intended to be characterised as  
10 in the above PCT application and/or otherwise as specifically provided herein.

The invention provides a panel-form loudspeaker having a distributed mode acoustic radiator and a first transducer coupled to the radiator to excite distributed mode  
15 resonance in the radiator, characterised by a second transducer coupled to vibrate the radiator. The first and second transducers may be adapted to operate in different frequency ranges. One of the transducers may be electromagnetic. One of the transducers may be piezo-  
20 electric.

The panel-form loudspeaker may be a second distributed mode acoustic radiator mounted on or in the first said radiator, and a resilient suspension coupling the first and second radiators, the first transducer being mounted wholly  
25 and exclusively on the first radiator and the second transducer being wholly and exclusively mounted on the second radiator. The second radiator may be mounted in an aperture in the first radiator.

BRIEF DESCRIPTION OF DRAWINGS

The invention is diagrammatically illustrated, by way of example, in the accompanying drawings, in which:-

Figure 1 is a diagram showing a distributed-mode  
5 loudspeaker as described and claimed in our co-pending International application No... (our case P.5711);

Figure 2a is a partial section on the line A-A of Figure 1;

Figure 2b is an enlarged cross-section through a  
10 distributed mode radiator of the kind shown in Figure 2a and showing two alternative constructions;

Figure 3 is a diagram of a first embodiment of distributed-mode loudspeaker according to the present invention;

15 Figure 4 is a diagram of a second embodiment of distributed mode loudspeaker according to the invention;

Figure 5 is a diagram of a third embodiment of distributed mode loudspeaker according to the invention;

Figure 6 is a diagram of a fourth embodiment of  
20 distributed mode loudspeaker according to the invention, and

Figure 7 is a perspective diagram of a transducer.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring to Figure 1 of the drawings, there is shown a panel-form loudspeaker (81) of the kind described and claimed in our co-pending International application No. (our case P.5711) of even date herewith comprising a  
5 rectangular frame (1) carrying a resilient suspension (3)

round its inner periphery which supports a distributed mode sound radiating panel (2). A transducer (9) e.g as described in detail with reference to our co-pending International applications Nos. (our cases P.5683/4/5) of even date herewith, is mounted wholly and exclusively on or in the panel (2) at a predetermined location defined by dimensions  $x$  and  $y$ , the position of which location is calculated as described in our co-pending International application No. (our case P.5711) of even date herewith, to launch bending waves into the panel to cause the panel to resonate to radiate an acoustic output.

The transducer (9) is driven by a signal amplifier (10), e.g. an audio amplifier, connected to the transducer by conductors (28). Amplifier loading and power requirements can be entirely normal, similar to conventional cone type speakers, sensitivity being of the order of 86 - 88dB/watt under room loaded conditions. Amplifier load impedance is largely resistive at 6 ohms, power handling 20-80 watts. Where the panel core and/or skins are of metal, they may be made to act as a heat sink for the transducer to remove heat from the motor coil of the transducer and thus improve power handling.

Figures 2a and 2b are partial typical cross-sections through the loudspeaker (81) of Figure 1. Figure 2a shows that the frame (1), surround (3) and panel (2) are connected together by respective adhesive-bonded joints (20). Suitable materials for the frame include lightweight framing, e.g. picture framing of extruded metal e.g.



aluminium alloy or plastics. Suitable surround materials include resilient materials such as foam rubber and foam plastics. Suitable adhesives for the joints (20) include epoxy, acrylic and cyano-acrylate etc. adhesives.

5        Figure 2b illustrates, to an enlarged scale, that the panel (2) is a rigid lightweight panel having a core (22) e.g. of a rigid plastics foam (97) e.g. cross linked polyvinylchloride or a cellular matrix (98) i.e. a honeycomb matrix of metal foil, plastics or the like, with  
10    the cells extending transversely to the plane of the panel, and enclosed by opposed skins (21) e.g. of paper, card, plastics or metal foil or sheet. Where the skins are of plastics, they may be reinforced with fibres e.g. of carbon, glass, Kevlar (RTM) or the like in a manner known  
15    per se to increase their modulus.

Envisaged skin layer materials and reinforcements thus include carbon, glass, Kevlar (RTM), Nomex (RTM) i.e. aramid etc. fibres in various lays and weaves, as well as paper, bonded paper laminates, melamine, and various  
20    synthetic plastics films of high modulus, such as Mylar (RTM), Kaptan (RTM), polycarbonate, phenolic, polyester or related plastics, and fibre reinforced plastics, etc. and metal sheet or foil. Investigation of the Vectra grade of liquid crystal polymer thermoplastics shows that they may  
25    be useful for the injection moulding of ultra thin skins or shells of smaller size, say up to around 30cm diameter. This material self forms an orientated crystal structure in the direction of injection, a preferred orientation for the

good propagation of treble energy from the driving point to the panel perimeter.

Additional such moulding for this and other thermoplastics allows for the mould tooling to carry  
5 location and registration features such as grooves or rings for the accurate location of transducer parts e.g. the motor coil, and the magnet suspension. Additional with some weaker core materials it is calculated that it would be advantageous to increase the skin thickness locally e.g.  
10 in an area or annulus up to 150% of the transducer diameter, to reinforce that area and beneficially couple vibration energy into the panel. High frequency response will be improved with the softer foam materials by this means.

15 Envisaged core layer materials include fabricated honeycombs or corrugations of aluminium alloy sheet or foil, or Kevlar (RTM), Nomex (RTM), plain or bonded papers, and various synthetic plastics films, as well as expanded or foamed plastics or pulp materials, even aerogel metals  
20 if of suitably low density. Some suitable core layer materials effectively exhibit usable self-skinning in their manufacture and/or otherwise have enough inherent stiffness for use without lamination between skin layers. A high performance cellular core material is known under the trade  
25 name 'Rohacell' which may be suitable as a radiator panel and which is without skins. In practical terms, the aim is for an overall lightness and stiffness suited to a particular purpose, specifically including optimising

contributions from core and skin layers and transitions between them.

Several of the preferred formulations for the panel employ metal and metal alloy skins, or alternatively a  
5 carbon fibre reinforcement. Both of these, and also designs with an alloy Aerogel or metal honeycomb core, will have substantial radio frequency screening properties which should be important in several EMC applications. Conventional panel or cone type speakers have no inherent  
10 EMC screening capability.

In addition the preferred form of piezo and electro dynamic transducers have negligible electromagnetic radiation or stray magnet fields. Conventional speakers have a large magnetic field, up to 1 metre distant unless  
15 specific compensation counter measures are taken.

Where it is important to maintain the screening in an application, electrical connection can be made to the conductive parts of an appropriate DML panel or an electrically conductive foam or similar interface may be  
20 used for the edge mounting.

The suspension (3) may damp the edges of the panel (2) to prevent excessive edge movement of the panel. Additionally or alternatively, further damping may be applied, e.g. as patches, bonded to the panel in selected  
25 positions to damp excessive movement to distribute resonance equally over the panel. The patches may be of bitumen-based material, as commonly used in conventional loudspeaker enclosures or may be of a resilient or rigid

polymeric sheet material. Some materials, notably paper and card, and some cores may be self-damping. Where desired, the damping may be increased in the construction of the panels by employing resiliently setting, rather than  
5 rigid setting adhesives.

Effective said selective damping includes specific application to the panel including its sheet material of means permanently associated therewith. Edges and corners can be particularly significant for dominant and less  
10 dispersed low frequency vibration modes of panels hereof. Edge-wise fixing of damping means can usefully lead to a panel with its said sheet material fully framed, though their corners can often be relatively free, say for desired extension to lower frequency operation. Attachment can be  
15 by adhesive or self-adhesive materials. Other forms of useful damping, particularly in terms of more subtle effects and/or mid- and higher frequencies can be by way of suitable mass or masses affixed to the sheet material at predetermined effective medial localised positions of said  
20 area.

An acoustic panel as described above is bi-directional. The sound energy from the back is not strongly phase related to that from the front. Consequently there is the benefit of overall summation of  
25 acoustic power in the room, sound energy of uniform frequency distribution, reduced reflective and standing wave effects and with the advantage of superior reproduction of the natural space and ambience in the

reproduced sound recordings.

While the radiation from the acoustic panel is largely non-directional, the percentage of phase related information increases off axis. For improved focus for the phantom stereo image, placement of the speakers, like pictures, at the usual standing person height, confers the benefit of a moderate off-axis placement for the normally seated listener optimising the stereo effect. Likewise the triangular left/right geometry with respect to the listener provides a further angular component. Good stereo is thus obtainable.

There is a further advantage for a group of listeners compared with conventional speaker reproduction. The intrinsically dispersed nature of acoustic panel sound radiation gives it a sound volume which does not obey the inverse square law for distance for an equivalent point source. Because the intensity fall-off with distance is much less than predicted by inverse square law then consequently for off-centre and poorly placed listeners the intensity field for the panel speaker promotes a superior stereo effect compared to conventional speakers. This is because the off-centre placed listener does not suffer the doubled problem due to proximity to the nearer speaker; firstly the excessive increase in loudness from the nearer speaker, and then the corresponding decrease in loudness from the further loudspeaker.

There is also the advantage of a flat, lightweight panel-form speaker, visually attractive, of good sound

quality and requiring only one transducer and no crossover for a full range sound from each panel diaphragm.

Figure 3 illustrates a panel-form loudspeaker (81) generally similar to that shown in Figures 1 and 2 and in which the distributed mode panel (2) is formed with a generally rectangular aperture (82) within its boundaries in which is mounted a second distributed mode sound radiating panel (4) with a resilient suspension (3) interposed between the respective panels. The panel (4) is constructed in the same manner as the panel (2), e.g. with a central core (22) separating skins (21). The panel (4) is driven by its own transducer (9) mounted wholly and exclusively on or in the panel (4) at a predetermined location to produce a high frequency acoustic output, while the panel (2) is driven by a separate transducer (9) to produce an acoustic output of lower frequency, so that the loudspeaker can readily encompass the whole acoustic spectrum. Such an arrangement may be useful if losses in the material of the panel tend to attenuate high frequencies. More than one transducer may be mounted on each or one of the panel to improve performance.

Figure 4 illustrates how a distributed mode panel (2) according to the present invention, and for example of the kind shown in Figures 1 and 2, can be driven to resonate by a pair (70,71) of transducers (9). The smaller one of the transducers (70) is a high frequency piezo transducer, e.g. of the kind shown in Figure 7, and the larger one of the transducers (71) is of the electrodynamic kind, e.g. as

shown in our co-pending International application Nos...  
(our files P5683/4/5).

The transducers (70,71) are driven by an amplifier  
(10) coupled in parallel to the respective transducers with  
5 the interposition of a step-up transformer (72) and  
matching resistance (73) in the line to the piezo  
transducer in view of its relatively high voltage  
requirement. If desired more than one transducer (70)  
and/or transducer (71) may be provided to improve the  
10 performance.

Figure 5 illustrates how a distributed mode panel (2)  
according to the present invention, e.g. of the kind shown  
in Figures 1 and 2, can be driven by a pair (70,74) of  
transducers (9), the transducer (70) being a high frequency  
15 piezo-electric transducer e.g. of the kind shown in Figure  
7 and the transducer (74) being a low frequency piezo-  
electric transducer of the kind shown in our co-pending  
International application No. (our file P.5684).  
Reference (75) indicates that the transducer (74) is  
20 weighted with a mass to increase its inertia. The  
transducers (70,74) are driven by an amplifier (10) to  
which they are connected in parallel, with resistors (78)  
interposed to provide a frequency dividing network. If  
desired more than one transducer (70) and/or transducer  
25 (74) may be provided to improve the performance.

Figure 6 illustrates how a distributed mode panel (2)  
according to the present invention, e.g. of the kind shown  
in Figures 1 and 2, can be driven by a pair (68,69) of

electrodynamic transducers, e.g. of the kinds shown in our co-pending International application Nos. (our files P.5683/4/5).

The transducer (68) is intended as a high frequency driver and is thus of low inductance, whereas the transducer (69) is intended as a low frequency driver and is of high inductance.

The transducers (68,69) are driven in parallel by an amplifier (10) with a capacitor (77) in the line to the transducer (68) to act as a frequency divider to pass most of the high frequency signal to the transducer (68). If desired more than one transducer (68) and/or transducer (69) may be provided to improve the performance.

Figure 7 shows a transducer (9) for a distributed mode panel (2) in the form of a crystalline disc-like piezo bender (27) mounted on a disc (118), e.g. of brass, which is bonded to a face of the panel (2), e.g. by an adhesive bond (20). In operation an acoustic signal applied to the transducer (9) via leads (28) will cause the piezo disc (27) to bend and thus locally resiliently deform the panel (2) to launch bending waves into the panel.



CLAIMS

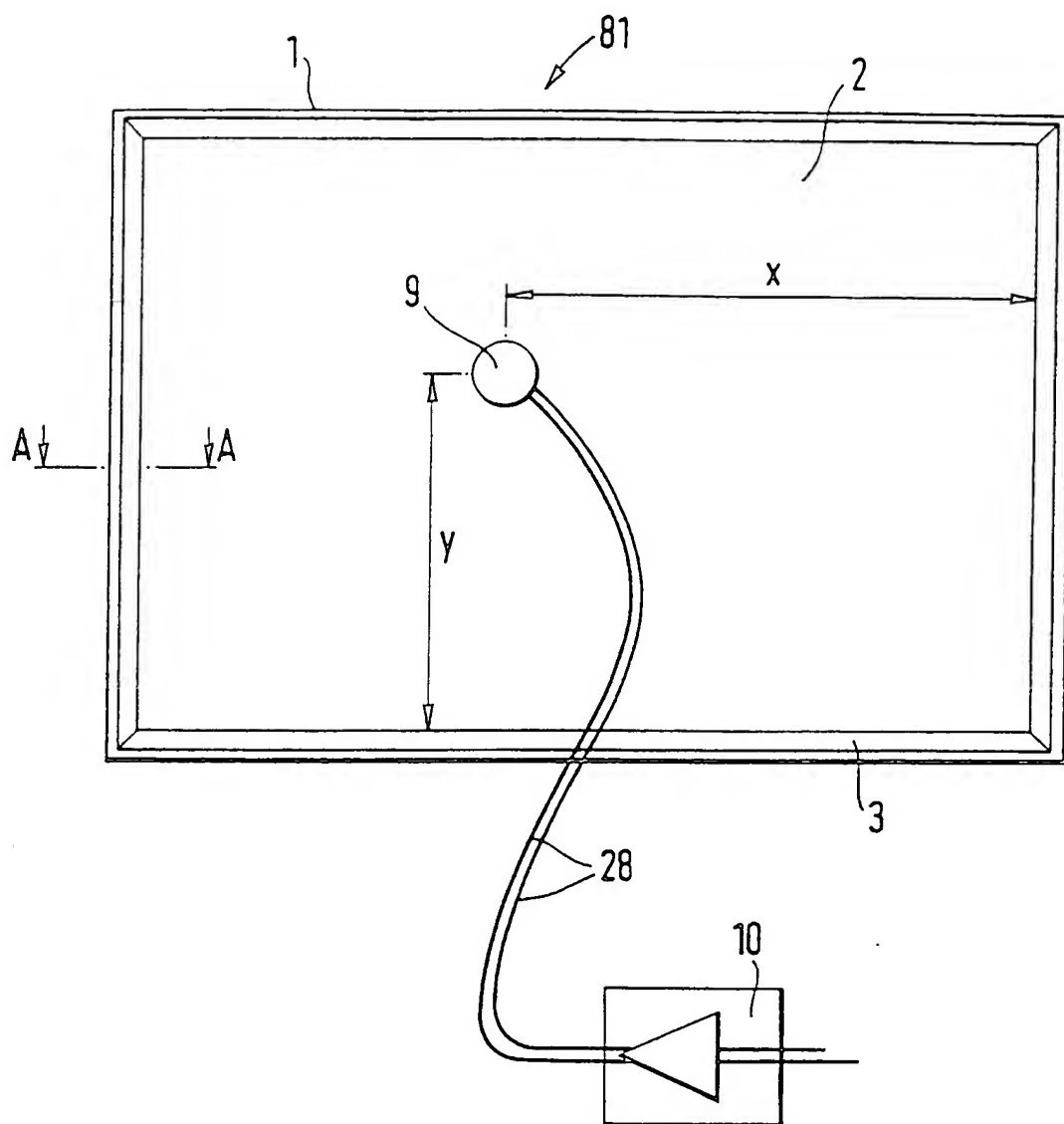
1. A panel-form loudspeaker having a distributed mode acoustic radiator and a first transducer coupled to the radiator to excite distributed mode resonance in the radiator, characterised by a second transducer coupled to  
5 vibrate the radiator.
2. A panel-form loudspeaker according to claim 1, characterised in that the first and second transducers are adapted to operate in different frequency ranges.
- 10 3. A panel-form loudspeaker according to claim 1 or claim 2, characterised in that the radiator comprises a stiff lightweight panel having a cellular core sandwiched between skins.
4. A panel-form loudspeaker according to claim 3,  
15 characterised by a frame supporting the panel, and by a resilient suspension by which the panel is attached to the frame.
5. A panel-form loudspeaker according to claim 4, characterised in that the frame surrounds the panel, and in  
20 that the suspension is attached to the edge of the panel.
6. A panel-form loudspeaker according to any preceding claim, characterised in that the first and second transducers are mounted wholly and exclusively on the radiator.
- 25 7. A panel-form loudspeaker according to any preceding claim, characterised in that one of the transducers is electromagnetic.
8. A panel-form loudspeaker according to claim 7,

characterised in that one of the transducers is piezo-electric.

9. A panel-form loudspeaker according to any preceding claim, characterised by a second distributed mode acoustic  
5 radiator mounted on or in the first said radiator, a resilient suspension coupling the first and second radiators, the first transducer being mounted wholly and exclusively on the first radiator and the second transducer being mounted wholly and exclusively on the second  
10 radiator.

10. A panel-form loudspeaker according to claim 9, characterised in that the second radiator is mounted in an aperture in the first radiator.

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*Fig. 1*

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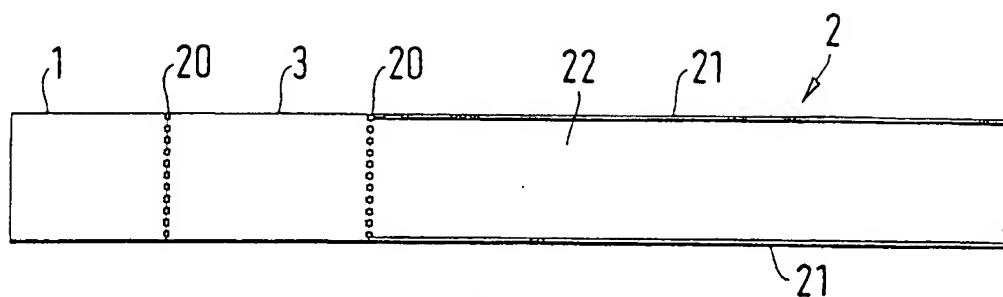


Fig. 2a

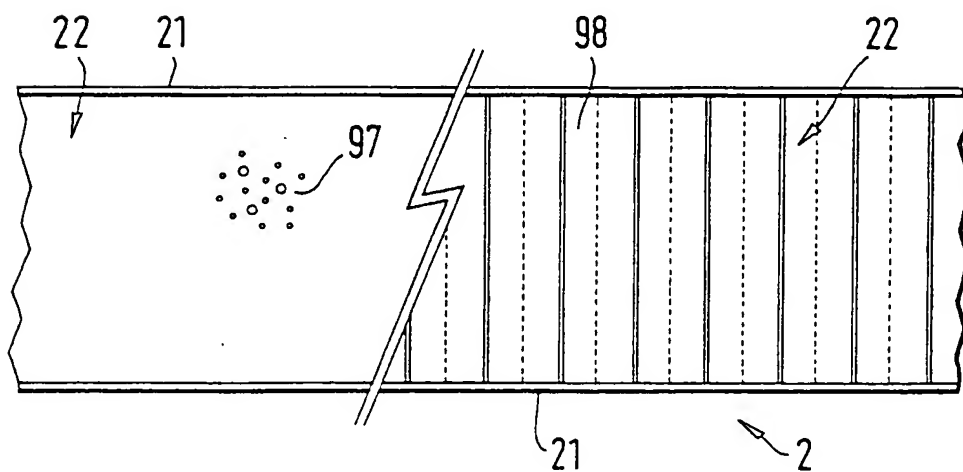


Fig. 2b

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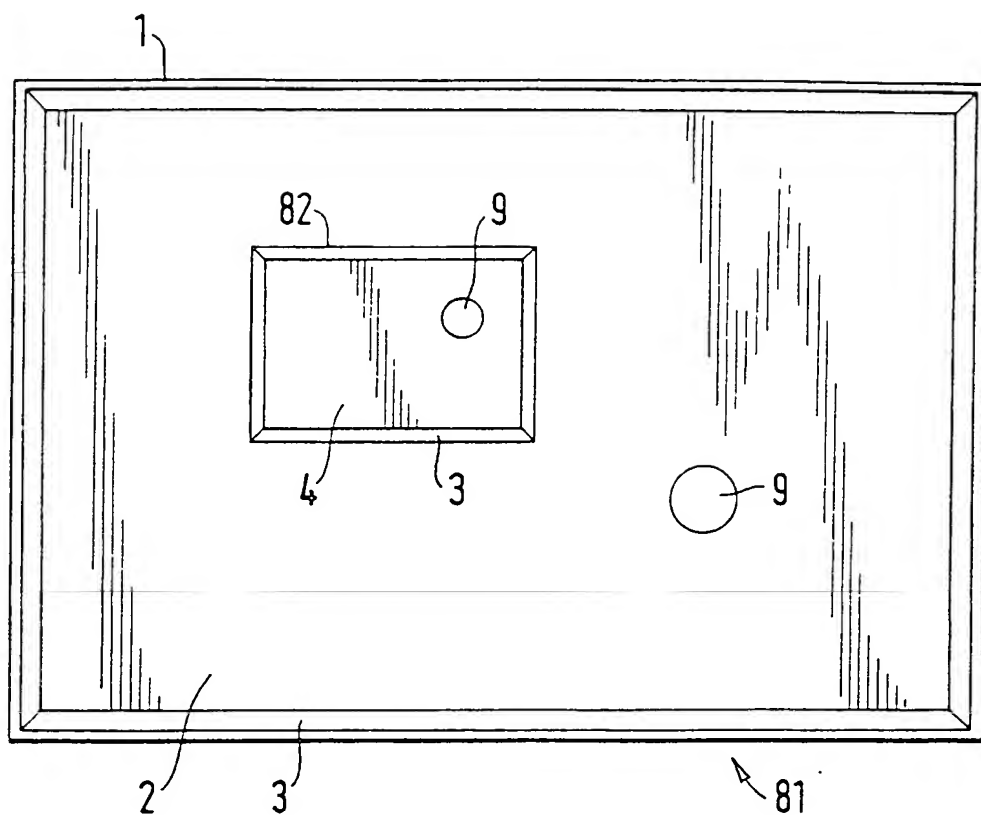
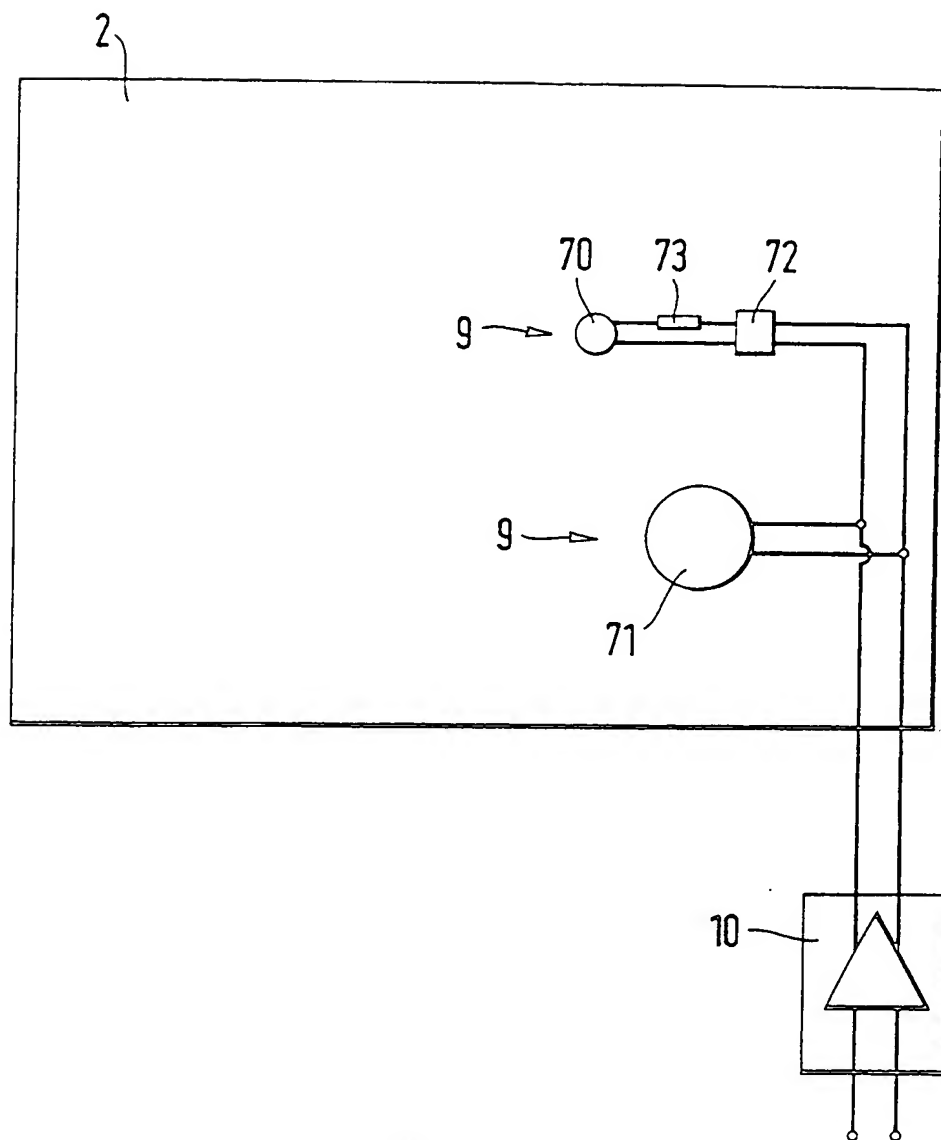
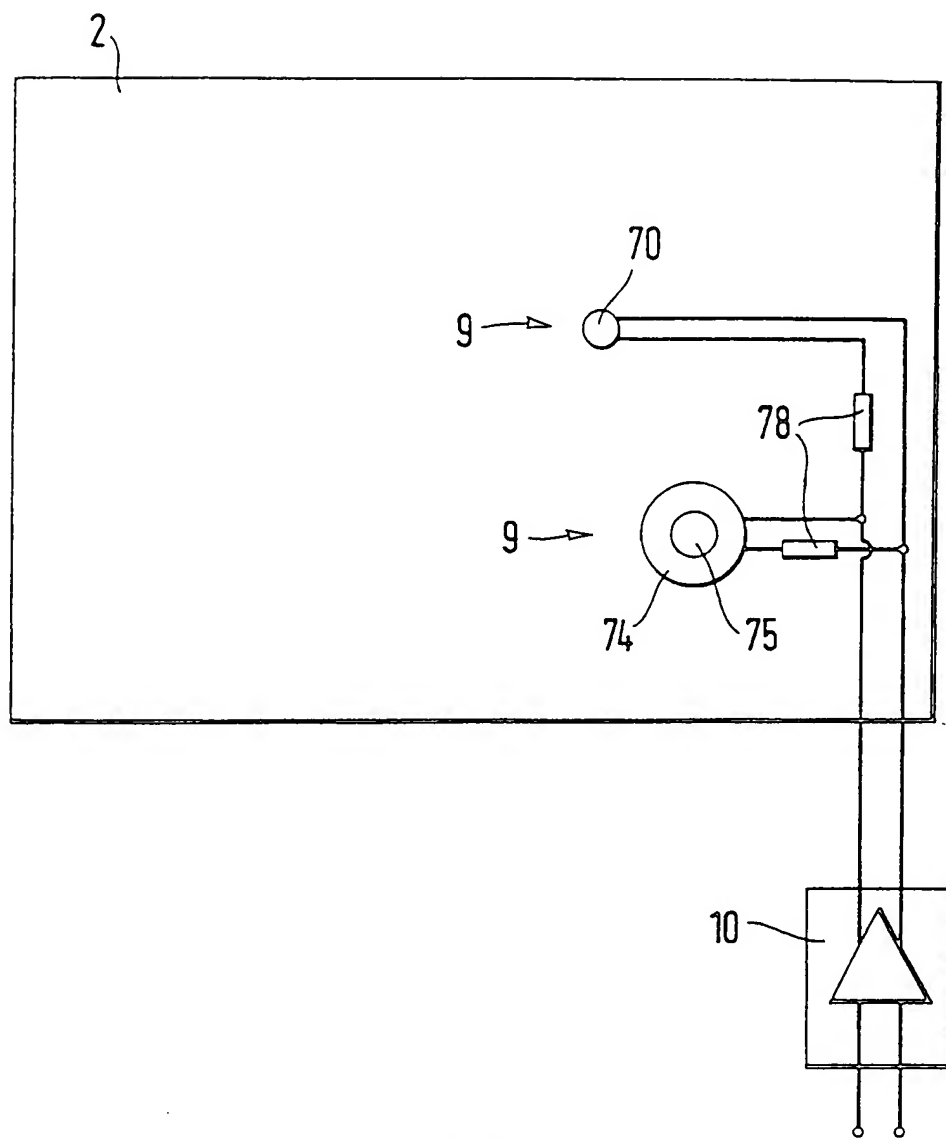


Fig. 3

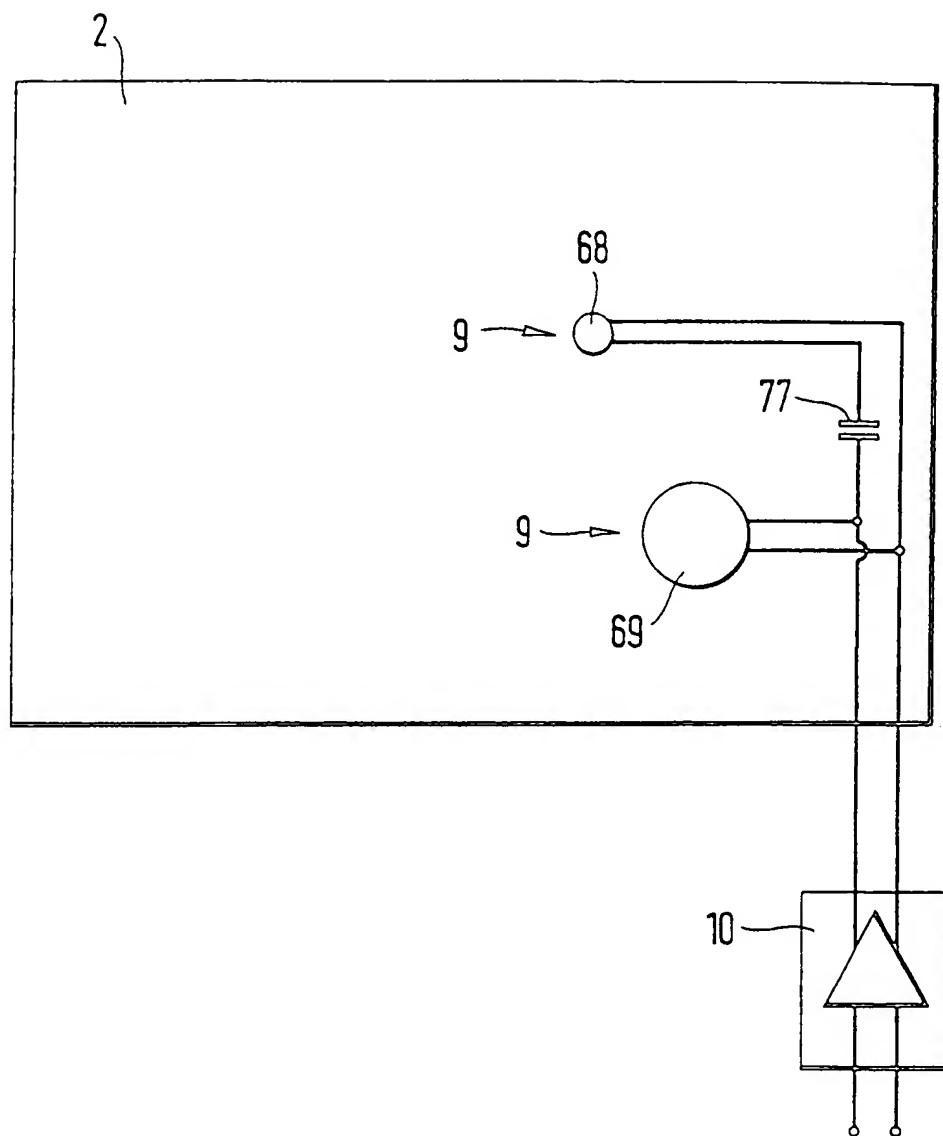
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*Fig. 4*

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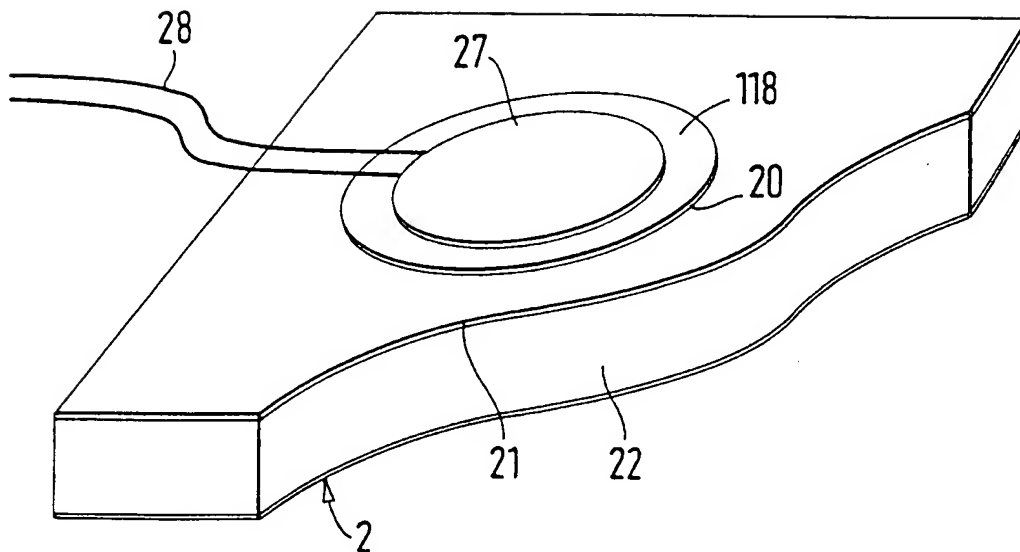
*Fig. 5*

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*Fig. 6*



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*Fig. 7*

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 96/02162

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 H04R1/02 H04R7/06 H04R1/26

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## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 92 03024 A (SECR DEFENCE BRIT) 20 February 1992	1
A		3
Y	& GB 2 262 861 A (SECR DEFENSE) 30 June 1993 cited in the application see page 5, line 4 - page 6, line 5; figures	1
Y	US 4 751 419 A (TAKAHATA) 14 June 1988 see column 11, line 10 - line 39	1
A	GB 2 010 637 A (SONY CORP) 27 June 1979 see page 2, line 77 - page 3, line 36	2,6,7
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Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 025 474 A (TANAKA ET AL.) 18 June 1991 see column 6, line 51 - column 7, line 45; figures 7-10 ---	4,5,7
A	EP 0 054 945 A (NISSAN MOTOR) 30 June 1982 see page 8, line 13 - page 12, line 16; figures ---	1,7
A	US 4 997 058 A (BERTAGNI) 5 March 1991 see column 5, line 52 - column 6, line 17; figures -----	1,9

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Information on patent family members

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GB-A-2010637	27-06-79	AT-B- 362000 CA-A- 1102444 DE-A- 2850786 FR-A- 2410410 NL-A,B,C 7811631 US-A- 4198550	10-04-81 02-06-81 18-10-79 22-06-79 29-05-79 15-04-80
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EP-A-0054945	30-06-82	JP-A- 57175445 JP-A- 57104396 US-A- 4514599	28-10-82 29-06-82 30-04-85
US-A-4997058	05-03-91	NONE	